

VARIATION IN SOME PORK QUALITY FACTORS WITHIN
AND BETWEEN SELECTED PORK MUSCLES

by

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B. S., University of Wisconsin, 1960

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Animal Husbandry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

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TABLE OF CONTENTS

INTRODUCTION.....	1
REVIEW OF LITERATURE.....	2
Effect of Intramuscular Fat on Pork Quality.....	2
Factors that Influence Intramuscular Fat Deposition in Swine.....	4
Relation of Color to Pork Quality.....	8
Factors Affecting Color of Muscle Tissue.....	9
Factors Which Influence Myoglobin Content.....	11
Variation of pH and Myoglobin Concentration.....	14
Effect of Iron and Copper on Color of Pork Muscle....	17
Water Holding Capacity of Meat Protein.....	20
Factors That Influence Meat Hydration.....	22
EXPERIMENTAL METHODS.....	26
History of Animals.....	26
Slaughter Procedure.....	27
Carcass Measurement.....	27
Gutting Procedure.....	29
Determination of Myoglobin.....	30
Expressible Moisture Determination.....	31
Fat Extraction and Moisture Determination.....	31
Color Determination.....	32
Determination of pH.....	32
Statistical Analysis.....	33
RESULTS AND DISCUSSION.....	33
Myoglobin.....	33

Effect of Ration on Myoglobin Concentration.....	36
Water Holding Capacity, Color and pH.....	38
Effect of Ration on Color Intensity, pH and Water Holding Capacity.....	42
Ether Extract and Total Moisture.....	44
SUMMARY.....	45
ACKNOWLEDGMENTS.....	48
LITERATURE CITED.....	49

INTRODUCTION

The subject of pork quality has received much attention the last five or six years. Unfortunately the emphasis placed on lean pork may have created a quality problem in muscle tissue. Also, soft watery pork has become more of a problem both to the consumer and processor. Most workers in the field of meats research had previously assumed that quality was not a problem in pork because of the young slaughter age of swine and the methods of processing used.

Extensive work made possible by new and more objective research techniques indicates the importance of various pork quality factors and their association with palatability and economic factors concerned with merchandising and consumption of pork.

Degree of intramuscular fat, color of lean, firmness of lean and fat, and maturity are factors associated with pork quality. There is considerable disagreement among research workers concerning the degree of importance of these factors in pork quality and how these factors may be altered.

Few reports were found in the literature concerning the influence of adding trace minerals to the swine ration on pork quality. Therefore, it was considered worthwhile to study various levels of iron, copper and sodium chloride in the diet of market swine. In addition, it seemed important to study the variation of some pork quality factors within and between selected, individual muscles.

REVIEW OF LITERATURE

The study of pork quality involves many basic concepts associated with the physiological and biochemical phenomenon of skeletal tissue. Pork quality is a composite of factors related to the sensory characteristics of a given cut of pork. Some of these factors are: intramuscular fat, color of lean, firmness and maturity.

Effect of Intramuscular Fat on Pork Quality

Intramuscular fat is any fatty tissue which is entwined around the muscle bundles and fibers within the structural framework of individual muscles. Marbling has been defined as intramuscular fat that is visible to the eye (Kauffman, 1960, p. 31).

The consumer preferred lean pork at time of purchase according to work by Birmingham (1954) at the Missouri Station. Kauffman (1961) reported a definite preference at time of purchase for unmarbled chops among 40 customers tested. However, as a result of home taste tests, 62 per cent preferred the marbled chops as compared to 18 per cent for the lean chops, while 20 per cent indicated no preference.

Sensory properties of pork muscle have been studied in relationship to fat content. Batcher and Dawson (1960) worked with 12 pork hams and loins and reported the degree of marbling in raw loin shows promise as a means of predicting the tenderness and juiciness of cooked loin and ham cuts. These workers

reported a high correlation between marbling score and intramuscular fat content of the longissimus dorsi muscle.

Murphy and Carlin (1961) of Iowa State University studied marbling of chops from 96 paired pork loins from carcasses that varied in fatback thickness from 1.0 to 3.2 inches. Marbling was similar in different sections, but degree of marbling increased slightly as the fatback increased. The amount of fatback on the carcass did not have a significant effect on tenderness, juiciness or flavor in the braised pork chops. However, shear-force measurements made on raw longissimus dorsi muscle indicated a slight increase in tenderness of raw muscle as fatback increased. Marbling had a significant positive correlation coefficient with both sensory tenderness and juiciness of braised pork chops. Kauffman (1960) and Saffle and Bratzler (1959) also found an association of intramuscular fat with sensory juiciness and tenderness.

Mean chew counts and shear values both showed significant correlations with two measures of marbling made on 36 loins (visual scores and intramuscular fat content), the less marbled loins being somewhat less tender. On the average, an increase of one per cent in intramuscular fat corresponded to a decrease of about 1.5 in chew count or 0.4 pounds in shear value (Harrington and Pearson, 1962).

Judge (1958) studied 54 pork loins and reported that a six member laboratory taste panel found that marbling was unrelated to tenderness but was associated with juiciness ($P < .01$) of broiled chops.

Batcher and Dawson (1960), Kauffman (1960) and Judge, et al. (1958), found a highly significant relationship between marbling score and intramuscular fat content.

Factors that Influence Intramuscular Fat Deposition in Swine

Age. Callow (1947) reported that as growth and fattening proceed, the extra chemical fat is laid down unequally. A larger and larger proportion of fat is deposited in subcutaneous and internal fatty tissue and a smaller proportion in muscular tissue.

Studies carried out by McMeekan (1940) found an increase in intramuscular fat up to 28 weeks of age, at which point his study was terminated. Kelly (1957) showed loin eye marbling to reach a maximum level at 125 pounds live weight with no further significant increase up to 205 pounds live weight. Kropf (1956) reported no significant difference in intramuscular ether extract of the longissimus dorsi between pigs weighing 145 pounds or 205 pounds at slaughter. However, pigs slaughtered at 145 pounds showed more intramuscular fat than those slaughtered at 45 or 85 pounds live weight.

Judge and co-workers (1959) found that age had no influence on marbling in pork. Helander (1959) has shown, however, a very definite and positive relationship of age to intramuscular fat in several other animal species. Fat content of the median head of the gastrocnemius muscle in cattle, rabbits and horses showed significant increase with age when young were compared with old

animals.

Ration. The ration fed growing swine may influence fat deposition. Kelly and co-workers (1957) indicated slightly lower (but not significant) values for loin and ham marbling when pigs were supplemented with aureomycin. However, Clawson and co-workers (1955) found the opposite to occur. He also showed a lowering of mg per cent blood fat due to antibiotic administration.

Quality of protein may influence the amount of intramuscular fat deposited. A high quality protein in the ration tended to lower per cent of marbling in loins (Kropf et al., 1959). In addition he showed differences in sex with regard to marbling deposition. Regardless of age, weight or ration in most cases gilts had a lower percent fat in the loin than did barrows. Judge (1959) also reported a tendency toward more marbling in loins from barrows.

Intramuscular fat in pork longissimus dorsi muscle was decreased as ration protein level was increased and by the practice of limited feed either by hand feeding or inclusion of high fiber (low TDN) components as reported by Merkel et al., (1958).

Starvation. Kauffman (1960) reported effects of starvation on intramuscular fat in the longissimus dorsi muscle. Three Chester White pigs, weighing about 260 pounds were starved for four weeks, receiving only water. Previous to this stress a biopsy sample was removed from the longissimus dorsi muscle at

the 10th rib and analyzed for total intramuscular fat. After a loss of 33 pounds, another sample was removed. The chemical analysis showed a 30 per cent decrease in intramuscular fat. This indicated that intramuscular fat may be used as a source of energy in swine receiving a submaintenance ration.

Breed. Judge and co-workers (1958) concluded from studies on 321 pigs of six different breeds, that there was a highly significant breed difference when marbling was compared. They ranked six breeds; Berkshires, Spotted Poland China, Yorkshire, Hampshire, Poland China and Landrace in descending order based on subjective marbling scores.

Clawson and co-workers (1955) reported breed differences in per cent extractable fat from a composite of meat from the left side of pork carcasses. They ranked three breeds, Chester Whites, Berkshires and Yorkshires in descending order based on ether extract.

Environment. Season of the year influenced intramuscular fat at the Ohio Station. Judge and co-workers (1959) found that hogs raised and slaughtered during cool weather possessed more highly marbled loin eye muscles.

Position and Type of Muscle. Batcher and Dawson (1960) related that fat content of one muscle was not always indicative of the fat content of other muscles in the same carcass. The longissimus dorsi muscle tended to have more fat than the ham. This is in agreement with results of Briskey et al. (1960).

Ramsbottom and co-workers (1945) in their study on various

beef muscles also found that muscles vary widely in fat content.

Satorius (1938) and Murphy (1961) reported level of intramuscular fat was similar in different sections of the longissimus dorsi muscle. Other workers, however, found great variation in intramuscular fat content of this muscle. McMeekan (1940) showed that the anterior and posterior portions of the loin of growing pigs contain a higher per cent of total fat than the middle portion. Carpenter et al. (1961) reported highly significant differences in extractable fat from three positions in the loin. The 6th lumbar position contained a significantly higher percentage of fat than the 7th or 13th rib locations, while the 13th rib location contained the least in each case. The composite sample of the left loin in each group tended to contain a higher extractable fat content than the right loin although this difference was not significant.

Bray and co-workers (1942) collected data on pork and beef loins. They found that the posterior section of beef loins was more tender than the anterior, but in pork no such difference in tenderness occurred. In another study Batcher and Dawson (1960) cut pork loins into two roasts for sampling by separating them at the 10th and 11th ribs. The palatability panel and the Kramer shear values indicated no significant difference in tenderness between the anterior and posterior samples of the longissimus dorsi muscles.

When studying the sampling of pork loins for cooking tests, Mackey and Oliver (1954) cut three pairs of pork loins into one

inch chops. The chops were numbered from one to 18 beginning at the rib end. In all cases, the first chop was more tender than the last, but there was more variation among animals than positions in the loin.

Weir (1953) divided both right and left longissimus dorsi muscles from six hogs into eight approximately equal samples. When mean panel scores and shear force values were recorded on a graph, it seemed evident to the author that the anterior was more tender than the posterior, and both were more tender than the central region.

The degree of marbling of the longissimus dorsi muscle between the 10th and 11th ribs showed promise as an indicator of the juiciness and tenderness of cooked pork loin (Batcher and Dawson, 1960). The correlation coefficient between marbling score and juiciness was highly significant. Correlation coefficients between marbling scores and tenderness were significant for the anterior and highly significant for the posterior portion of the muscle.

Relation of Color to Pork Quality

Tenderness and Flavor. The color or degree of pigmentation is a factor influencing the consumer acceptance of meat. Only about 82 per cent of the flavor influencing materials have been accounted for in pork and color is associated with 18 per cent of the total (Kurtz, 1959).

Muscle color was significantly correlated with tenderness.

Dark tissue was less tender than light muscle as reported by Judge and co-workers (1958).

According to Husaini et al. (1950) muscle color showed no relationship to beef tenderness at 3 days post-mortem, but a very significant correlation to tenderness was observed at 15 days post-mortem. These observations were interpreted as indicating the importance of muscle plasma, as represented by muscle hemoglobin in the tenderness of beef.

Factors Affecting Color of Muscle Tissue

Under certain conditions, treatment immediately prior to slaughter may have a pronounced effect on color, but variation in color may also be attributed to physiological and/or hereditary factors.

Sex and Breed. Color was not affected by sex; however, breed differences were highly significant. Some breeds produced soft, light colored muscle while others produced firm, dark colored muscle (Judge et al., 1959).

Age and Environment. Judge and co-workers (1959) also reported that age did not affect color, but pigs grown and fattened during cool weather yielded darker colored muscle tissue. A high incidence of soft, watery muscle during warm, summer months has been reported by Wismer-Pederson (1959). Sayre and co-workers (1961) placed market weight swine in cold water for 30-40 minutes to stimulate a severe environmental stress. The extreme change in environment from warm to cold temperature

decreased the initial muscle glycogen level with a resultant decrease in lactic acid concentration and an increase in color intensity of the chilled muscle.

External Finish. Saffle and Bratzler (1959) reported color of the longissimus dorsi increased in lightness as the degree of external finish increased.

Myoglobin. The chemistry of meat color is primarily the chemistry of one pigment, myoglobin. Myoglobin is a conjugated protein, similar in function to the blood pigment hemoglobin in that both serve to complex with oxygen. Although their functions are similar, their roles are different; hemoglobin acts as an oxygen carrier in the blood stream, whereas myoglobin is essentially a storage mechanism for oxygen in the cells (American Meat Institute Foundation, 1960, p. 88).

Myoglobin Structure and Function. The structure and function of myoglobin must be understood to understand its association with meat color. Myoglobin is described as a complex protein which has a protein portion and a non-peptide moiety which is complexed to the peptide chain. The protein moiety is known specifically as globin. The non-peptide portion is called the heme, and it is composed of two parts: an iron atom and a large planar ring, the porphyrin. The porphyrin is made up of four identical sub-units, each consisting of the heterocyclic compound pyrrole, linked together by methene bridges. There are three different kinds of side chains: methyl, vinyl, and propyl. The particular isomer found in myoglobin is known as protoporphyrin IX.

The ring structure will form stable complexes with a large number of metals, but complexes formed with two of the transition elements, cobalt and iron, are the most important biologically. The complexes with iron are known as hemes and when they are bound to the globin through side chains, the resulting compounds are myoglobin and hemoglobin.

There are two important differences between hemoglobin and myoglobin. First, although hemoglobin has four times the molecular weight of muscle pigment, its oxygen binding equivalence is the same because it has four heme groups per molecule. Second, the binding of heme is not the same in the two compounds and a higher oxygen affinity is found in muscle pigment (American Meat Institute Foundation, 1960, p. 88).

Factors Which Influence Myoglobin Content

Chilling. Since color changes seemed to occur during the chilling period, myoglobin determinations were conducted by Briskey et al. (1959) before and after the chilling period to clarify the position of myoglobin in the creation of muscle color. These data clearly demonstrate that even though there were changes in color, there was no evidence of myoglobin destruction during the chilling process.

Exercise and Age. From a series of studies (Millikan, 1939; Lawrie, 1953; Ginger et al., 1954), it was observed that myoglobin concentration increased with age and activity of muscle tissue.

Briskey and co-workers (1959) exercised pigs on a treadmill.

When repeated exercise was given, the hogs seemingly adjusted themselves rapidly to this type of treatment. The hams from these hogs were very similar in color to non-exercised controls. Fasted and full fed animals that were subjected to single, severe exercise possessed muscles that were dark in color. The increase in the intensity of color of the severely exercised lots was not solely a reflection of increased pigment quantities. It was postulated, however, that this increase in color intensity was due to a change in muscle consistency as a result of its higher pH.

Lawrie (1953) reported an increase in myoglobin content when muscle tissue was influenced by enforced activity, provided the latter continues over an extended period of time. Over short periods, even the most severe exercise elicited no such response.

Position of Muscle. Schweigert (1956) showed that light colored muscle of fresh hams had about one-half as much myoglobin as the darker muscle.

Heritability. Wilson et al. (1959) studied myoglobin concentration in ham muscles from pigs representing three breeds of hogs; Poland China, Duroc and Chester White. The contrast between the light (biceps femoris) and dark muscles or the degree of "two-toning" was most marked in the Poland China breed, in which the dark muscles contained almost twice as much myoglobin as the biceps femoris. The least degree of "two-toning" was observed in the Chester White breed in which the darkest muscles contained only one-third more pigment than the biceps femoris. The ham

from the Durocs contained an average of 1.24 mg of myoglobin per gm in the biceps femoris and 1.80 mg per gm in the darker muscles, and were intermediate in the degree of "two-toning". For the samples studied, the degree of "two-toning" was more closely related to the amount of myoglobin in the dark muscles than the amount of myoglobin in the light colored muscle.

Hydrogen Ion Concentration. Color of muscle tissue was greatly influenced by pH. In a series of studies (Briskey et al., 1959; Judge et al., 1959; Lawrie, 1958; Scaife, 1955; Sair, 1938), it was indicated that color intensity was positively related to pH. Darker colored muscle usually had a higher pH than lighter colored muscle tissue.

Bate-Smith (1948) reported the processes concerned with formation of acid in muscle. He found that the breakdown of glycogen into lactic acid with a release of energy was the major process responsible for acid formation in muscle tissue.

McCarthy and Mackintosh (1953) suggested that muscle pH represented a balance between the buffering capacity and the presence of acidic substances.

Muscle Glycogen. Bate-Smith (1948) reported an animal killed after stress will have a low glycogen content. In periods of alternate work and rest, the glycogen content can be built up to high levels. In a well nourished animal, recovery of glycogen even after exhaustive work is usually quite rapid, and the level reached may exceed the original resting level.

According to Briskey et al. (1959), fasted and full fed

animals that were subjected to single, severe exercise possessed muscles that were high in pH value and dry in appearance.

A low carbohydrate ration was effective in experimentally producing hams which were darker in appearance and firmer in structure than their controls. Conversely medium and high sucrose rations produced hams which were lighter in color and softer in structure than their controls. The ration significantly altered pH and glycogen values of the gluteus medius and biceps femoris but had a smaller effect on the characteristics of the rectus femoris and pectoralis profundus (Briskey et al., 1960).

Variation of pH and Myoglobin Concentration

Fresh and Chilled Muscle. Briskey and co-workers (1959) classed hams into four groups based on appearance of cut surface of the ham where separated from the loin: pale, two-toned; two-toned, normal, and dark. The gluteus medius, gluteus accessorius and gluteus profundus of the above groups were not significantly different in myoglobin content. The pH values of the gluteus medius muscle 40 minutes after slaughter were significantly ($P < 0.05$) lower for the two-toned groups than the normal and dark classes. After 24 hours the pale, two-toned and the two-toned group continued to drop in muscle pH and were significantly ($P < 0.01$) lower than the dark and normal group. A similar situation existed for the gluteus accessorius and gluteus profundus; however, a significant difference was only exhibited between the extreme classification; namely pale, two-toned; and dark. The pH

values of all fresh tissue 2 minutes after slaughter were similar for all muscles regardless of final classification. Briskey et al. (1959) point out that this similarity of pH values supports the common contention that pH of live tissue is physiologically controlled within limits compatible with the biological system.

Chilled samples of gluteus medius, gluteus accessorius, rectus femoris, biceps femoris, longissimus dorsi, pectoralis profundus, serratus ventralis and teres major were studied. The pH values at time of slaughter ranged from 6.1 to 7.1, showed extreme variation between animals, and were not significantly different between muscles. The average ultimate 24 hour pH values ranged from 6.06 for the gluteus accessorius to 5.60 for the longissimus dorsi. The two dark ham muscles, gluteus accessorius and rectus femoris had pH readings of 6.06 and 6.01 respectively and the lighter muscles, gluteus medius and the biceps femoris had average pH readings at 5.68 and 5.83 respectively. The longissimus dorsi had the lowest pH of 5.60 and the lowest myoglobin concentration of 2.17 mg/g. Even though great variation existed, the total water and myoglobin of individual muscles did not vary significantly between animals although differences were noted in the appearance of the chilled muscle. The muscles that exhibited relatively high ultimate pH values showed lower initial glycogen values and greater myoglobin concentration (Briskey et al., 1960). Scaife (1955) also found a greater myoglobin concentration at higher pH values in the semimembranosus, semitendinosus and rectus femoris.

Further work by Briskey and Wismer-Pederson (1961a) indicated that at least four distinct types of post-mortem pH patterns existed in pork muscle tissue. The patterns are: (1) a slow, gradual decrease to an ultimate pH of 5.7 - 6.3; (2) a gradual decrease to about pH 5.7 at 8 hours and an ultimate pH of 5.3 - 5.7; (3) a relatively rapid decrease to a pH of about 5.5 at 3 hours, with an ultimate pH of 5.3 - 5.6; (4) a sharp, significant decrease to pH of about 5.1 at 1 1/2 hours and a subsequent elevation to 5.3 - 5.6. The first three types were acceptable in muscle structure, color and water retention, whereas type 4 represented pale, exudative tissue with soft, inferior structure. The violent nature of the post-mortem changes in tissue with type 4 pH pattern were unexplained but there is a possibility it may be due to a more rapid onset of rigor mortis in the tissue.

Briskey and Wismer-Pederson (1961b) determined the association of muscle biopsy sample characteristics from six barrows with post-mortem pH pattern. The data imply that the biopsy samples from pigs that ultimately showed the severe depression and subsequent elevation in pH pattern contained greater total glycogen, lower percentage of acid-soluble glycogen and greater phosphorylase activity. Similarly, these pigs possessed a smaller pyruvic acid pool and a greater lactic acid concentration in muscle biopsy samples.

Variation Within Muscle. Lawrie (1958) reported locations in the seminembranosus only 1 cm apart that had ultimate pH

values of 4.94 and 5.56.

McCarthy and Mackintosh (1953) found an anterior-posterior pH variation in pork loin eye muscle. The 48 hour muscle pH value decreased significantly from the blade end to the center sample to the loin end sample. The study also indicated the ultimate pH of the psoas major appeared to have a higher value than the ham. Ginger (1954) also observed a color difference within a particular muscle.

Effect of Iron and Copper on Color of Pork Muscle

Iron and copper play an essential role in hemoglobin formation. Copper is not a part of the hemoglobin molecule, but it is necessary so the body can utilize iron for formation of hemoglobin. Both iron and copper are constituents of many enzymes in the pigs body (Cunha, 1957, p. 61).

Functions and Requirements of Iron. The use of iron by the mammal has been explained by Barron (1954). Porphyrin molecules easily accept metals. Iron enters the center of the porphyrin squares forming hemochromogens. In living cells, porphyrins are found in combination with protein, in such compounds as hemoglobin, the protoporphyrins, and the cytochromes. They are electroactive, readily oxidized by atmospheric oxygen, and act as catalysts for many reactions. Hemoglobin can combine reversibly with molecular oxygen without changing the valence of the iron (ferrous), thus making transfer of oxygen to the cell possible.

Sheehy (1932) reported that the hemoglobin content of the

blood of pigs falls rapidly after birth and continues to fall until the milk is supplemented with a food rich in iron. After the pigs begin to consume food containing Fe and Cu, the anemia disappears.

According to Cunha (1957, p. 63), baby pig anemia can be prevented by swabbing the sows' udder with ferrous sulfate or giving pigs iron pills. Ten to 15 milligrams of iron daily for the first six weeks is adequate to maintain normal hemoglobin levels in suckling pigs. After that, the pigs usually get enough iron in normal rations unless there is an iron deficiency in the soil. Fifteen milligrams of iron per pound of total ration has been recommended as a level that will permit normal growth and reproduction.

Functions and Requirements of Copper. Wintrobe, Cartwright and Gubler (1953) reviewed the functions of copper in swine nutrition. They stated that although the mechanism is not completely understood, copper promotes the absorption of iron in the gastrointestinal tract, facilitates mobilization of iron from the tissues, and is necessary for the utilization of iron in hemoglobin synthesis. It influences iron metabolism in the mucosal cells, liver cells, and bone marrow.

Cunha (1957 p. 64) reported that usually there is enough copper in growing-fattening rations for pigs. The amount of copper needed is small; two milligrams of copper per pound of total ration seem sufficient to prevent deficiency.

Supplementation of Calf Rations. At the University of

Wisconsin, workers studied the effect of four calf rations on veal quality (Bray et al., 1959; Hanning et al. 1957; Niedermeier et al., 1959). Calves which received a copper and iron supplement had the highest level of hemoglobin. After the calves were slaughtered at six weeks of age, the loins from calves receiving the high copper and iron had a significantly higher amount of myoglobin and were darker in color than veal from other lots.

Both roasts and chops from the animals fed iron and copper supplements were significantly more tender as indicated by shear strength and were rated more tender by the judges.

Effect of Nutrition Level on Beef. Jacobson and Fenton (1956a and b) investigated the effect of feeding 60 per cent, 100 per cent and 160 per cent of a recommended basal ration to Holstein bulls and heifers. The meat of animals on the highest nutritional level contained 20 to 30 per cent more iron than meat from animals on the lowest level. There was an increase in redness of muscle color as the plane of nutrition increased. The iron content of the ration and color values of the muscle were positively correlated. No significant differences in shear values of longissimus dorsi muscle that could be attributed to ration were observed. However, when compared by a taste panel, the loins from the 160 per cent basal lot were significantly more tender than loins from the 60 per cent basal lot.

Henry and co-workers (1961) carried out repeated injections of iron-dextran in the ham of swine at 5, 7, 11, and 17 weeks of age. Hemoglobin and hematocrits increased though 9 weeks of age.

At 16 and 22 weeks of age the injected pigs had lower hemoglobin and hematocrits than the control pigs. Repeated injections of iron apparently did not affect the myoglobin concentrations or surface color of the semimembranosus muscle.

Water Holding Capacity of Meat Protein

Post mortem pH changes have been observed which might contribute to increased protein hydration during post mortem aging. The suggestion is offered that the important qualities of meat such as tenderness, cooking shrink, amount of drip on thawing of frozen cuts and degree of rehydration after dehydration may all be primarily related to the degree of hydration of the meat protein. All properties of meat of prime importance to the processor and consumer are primarily based on the water holding capacity of meat protein (Wierbicki et al. 1956).

Water holding capacity means the ability of meat to hold fast its own or added water during application of any force (pressing, heating, chewing, grinding and so on). The cause of this effect is the interaction between meat proteins and water. This interaction is called "meat hydration" by Hamm (1959).

According to Hamm (1959) water bound by the muscle protein is influenced by the net charge and stereo effect. The peptide chains of the proteins carry some free electric charges, presented by negative carboxyl groups and the positive amino groups; furthermore, they contain other so called polar groups such as sulfhydryl groups. Also water is a dipole which means negative charge of oxygen

and positive charge of hydrogen do not coincide. Therefore, water is a molecular magnet. This magnet is attracted by all kinds of polar groups in the protein. The polar groups of the protein cause the water binding and there is reason to believe that this electromagnetic power concerns not only the water bound immediately in the first layer but it also operates at some distance. However, not all charged groups may bind water. Groups which compensate their charges by an inter or intramolecular salt cross-linkage are not available for attracting water molecules. Therefore, only the net charge of protein has an influence on the water holding capacity. This kind of hydration Hamme called the net charge effect.

The many degrees of meat hydration are not due only to a change of the net charge of proteins. The peptide chains of native proteins are connected by cross linkages, for example by salt-linkages, bivalent metals, or hydrogen bonds. In this molecular network a number of charged groups are not available for water binding because of stereo reasons, which means there is not space enough for the water molecules. By cleavage of cross linkages the peptide chains become more flexible and now water can become attached to the polar groups. Hamme called such changes of meat hydration, which are not due to changes of net charge, the stereo effect.

Factors That Influence Meat Hydration

Color and Hydrogen Ion Concentration. Water holding capacity is positively related to both color intensity and pH (Judge et al., 1958; Bate-Smith 1948; Briskey et al., 1959 and 1960; Lawrie 1958; Wismer-Pederson, 1959). Dark, firm muscle was higher in pH and lower in free water than was light, soft muscle.

The influence of pH on meat hydration is a typical example of the importance of protein net charge. The isoelectric point of muscle is about pH 5.0. At this pH the amount of positive charge is equal to the amount of negative charge. At the isoelectric point the net charge of muscle protein is at a minimum. Therefore at this pH the meat hydration has a sharp minimum. The normal pH of meat is about 5.5 which is close to the isoelectric point and therefore the water holding capacity is quite low (Hamm, 1959).

According to Briskey and co-workers (1959) there were no significant differences in the expressible water to total water ratios among four classes of fresh hams. Hams were classed into four groups: pale, two-toned; two-toned, normal, and dark color. These findings seemed to be related to the similarity in pH values at this stage. The relative amount of expressible water however, increased significantly during the chilling process. This increase was the greatest from muscles which possessed high concentrations of glycogen at the time of slaughter.

Briskey and Wisner-Pederson (1961) recorded continuous pH and temperature changes during post-mortem chilling. Carcasses that had a sharp, significant decrease to pH of about 5.1 at 1 1/2 hours and a subsequent elevation to 5.3 - 5.6 possessed pale, exudative tissue with soft inferior structure. The chilling rate of the individual muscle may also be an important factor affecting pH pattern and ultimate muscle structure.

Swift and Berman (1960) reported considerable variation of both glycogen and buffering capacity among eight muscles studied. However, the muscles showed characteristic patterns in regard to pH and water retention since the eight muscles studied all contained residual glycogen when the ultimate pH was attained, the relatively high characteristic pH of certain muscles could not be attributed to lack of glycogen alone.

Histological Factors. Histologically there are several unusual features and abnormalities related to pH (Lawrie, 1958). Muscles with an ultimate pH of 5.3 had discernable cross-striation, but the muscle fibers were frequently twisted and broken. At pH 5.1 the protein gel in the interior of more than half of the fibers appeared to have coagulated. At pH 4.9 all fibers were abnormal: some of these showed no cross-striations but had manifest longitudinal markings; others still had cross-striations, but were both twisted and finely corrugated.

Wisner-Pedersen (1959) histologically examined samples of pork loin with different pH values. No systematic difference

in the appearance of the fibers and cell structure was observed between the muscles with high and low pH.

Variations in the distribution of water in bovine longissimus dorsi, semimembranosus, serratus ventralis and rectus abdominus muscles were histologically studied by Lockett et al. (1962). It was reported that extracellular space of muscle tissue was positively correlated with the water-protein ratio, whereas intracellular water content was negatively correlated. The evidence indicates that, in the muscles that characteristically contain a relatively high proportion of water to protein, the additional water is located in extracellular spaces.

Effect of Electrolyte Content, Fat and Protein. Swift and Berman (1959) reported considerable variation with respect to water retention in eight muscles studied. Statistically significant correlations were obtained between water retention and pH, fat content and ratio of moisture to protein. A direct, highly significant correlation was found between water retention and zinc content, in contrast to an inverse relationship found between water retention and either calcium or magnesium content. This information indicates that zinc differs in an important aspect from the two other ions. The possibility that zinc may participate in determining pH as a component of an enzyme system is pointed out.

A highly significant negative correlation was calculated between water-retention and protein content (protein content was calculated using the generally based relationship, per cent $N \times 6.25$ equals per cent protein). This inverse relationship is

paradoxical inasmuch as protein is the component of muscle assumed to be principally responsible for water retention.

Sodium chloride will increase water holding capacity by the influence of the chloride ion rather than the sodium ions (Hamm, 1959). Salt cross-linkages between peptide chains may be split off by binding of chloride ions and there is an increase of meat hydration of both the net charge and stereo effect (Hamm, 1959).

Sherman (1961) and Hamm (1959) indicate that polyphosphates and citrates influence water retention due to their relatively high ionic strengths and to their influence on meat pH. These salts work mainly by their ability to form strong complex compounds with alkaline earth metals. They eliminate bivalent cations in meat, especially magnesium.

Effect of Zinc Containing Enzymes. Six different muscles from three bovine animals were studied by Berman and Morris (1961). Considerable variation was found in levels of zinc, lactic dehydrogenase, glutamic dehydrogenase, and carbonic anhydrase. A highly significant direct correlation was found between pH and zinc content, and a highly significant inverse correlation between lactic dehydrogenase and pH. Lactic dehydrogenase was significantly correlated with soluble nitrogen content. No relation was found between glutamic dehydrogenase, carbonic anhydrase and pH.

Effect of ATP. During the first 24 to 48 hours after slaughter, hydration decreases very markedly. The post-mortem formation of lactic acid by glycolysis results in a drop of pH

and such a drop decreases meat hydration. However, only one third of the post-mortem hydration drop is explained by decreased pH. Freshly slaughtered meat contains adenosinetriphosphate (ATP), an organic polyphosphate. During the first 24 hours after death the ATP is broken down to adenosinediphosphate (ADP) and adenosine-monophosphate and finally, after deamination, to inorganicmonophosphate (IMP). The post-mortem drop of hydration is proportional to the decrease of ATP and accounts for two thirds of the loss of hydration. ATP has the ability to form strong complexes with alkaline earth metals. By the breakdown of ATP, its bound cations are released because AMP and IMP have a much lower ability to form complexes. The free cations can be built into the protein structure causing a tighter network with lower hydration (Hamm, 1959).

Variation within Muscles. Urbin and co-workers (1962) reported variation within the cross-sectional area of the loin when free-moisture determinations were made by a modification of the Graw-Hamm procedure. The medial portion of the longissimus dorsi had significantly lower free moisture values than the lateral portion.

EXPERIMENTAL METHODS

History of Animals

Fifty-six Hampshire swine were divided into seven lots according to the table of random numbers suggested by Snedecor (1959) with four barrows and four gilts in each lot. These pigs

were fed the ration listed in Table 1.

The feed was pelleted and fed free choice with water available at all times from approximately eight weeks of age to slaughter weight (about 210 pounds). To prevent ingestion of iron, copper and sodium chloride from other sources, the hogs were raised on concrete lots fenced with wooden boards and fed from galvanized feeders. All minerals were removed from the water by use of a Culligan water conditioner.

Slaughter Procedure

The animals were slaughtered in the Kansas State University meat laboratory by normal slaughter procedures. The hogs were delivered to the meat laboratory approximately 12 hours before slaughter. An effort was made to slaughter animals at 200 pounds and therefore they were taken off test between 205 to 210 pounds. All hogs were dressed essentially packer style, head off, leaf fat removed and hams unfaced.

Carcass Measurement

The carcasses were chilled at a temperature of 30-34 degrees. The carcasses were cut approximately 24 hours after slaughter and each carcass was weighed, fatback thickness and carcass length was measured.

Table 1. Ration fed to animals in each lot.

: Animal :		Ration	
Lot :	numbers:		
I	40-47	Control Ration ¹	
		Ingredients	Quantity
		Milo	790 lbs
		Soybean oil meal	95 lbs
		Meat scraps	50 lbs
		Alfalfa meal (dehyd.)	50 lbs
		"Aurofac" ²	5 lbs
		Iodized salt	5 lbs
		Vitamin A	400,000 IU
		Vitamin B ₁₂	5,000 Ug
		B complex vitamin	1/2 lb (Merck 58-A)
		MnSO ₄ .H ₂ O	75 gms
II	48-55	Control Ration + 400 gms Na ₂ Ca ₂ NEDTA (ethylene-diaminetetraacetate)/1000 lb ration	
III ³	56-63	Corn	685 lbs
		Skim milk	305 lbs
		"Aurofac"	5 lbs
		Iodized salt	5 lbs
		Vitamin A	400,000 IU
		Vitamin B ₁₂	5,000 Ug
		Vitamin B ⁴ complex	1/2 lb (Merck 58-A)
		CaCO ₃	5 lbs
		MnSO ₄ .H ₂ O	108 gms
IV	64-71	Control Ration + ferrous sulfate (2779 gms) and cupric sulfate (199 gms)	
V	72-79	Control Ration + ferrous sulfate (5987 gms) and cupric sulfate (455 gms)	
VI	61M-68M	Control Ration - without added sodium chloride	
VIIa	71M-78M	Control Ration	
VIIb	71M-78M	Control Ration ⁴ + Sodium chloride (50 lbs)	

¹Contains 40.15 mg of iron and 6.79 mg of copper per lb of ration.

²Commercial auromycin and vitamin B₁₂.

³Ration for lot 3 contained 9.08 mg of iron and 2.82 mg of copper per lb of ration.

⁴Animals were moved from Lot VIIa to VIIb when they reached 180 lbs.

Cutting Procedure

The cutting procedure used followed those described by the pork evaluation committee at the 1952 Reciprocal Meat Conference with the following exceptions. The rough shoulder was removed at the posterior edge of the first rib. The ham was removed at a point halfway between the anterior point of the aitch bone and the first sacral vertebra and at a right angle to the long axis of the ham. The ham was skinned to 1/4 inch of fat. The psoas major was dissected from the right loin and the loin was then divided in three sections by cutting as follows:

A - anterior	posterior edge of third rib to posterior edge of tenth rib
C - center	posterior edge of the tenth rib to anterior edge of first lumbar vertebra
P - posterior	anterior edge of first lumbar vertebra to anterior edge of hipbone

The longissimus dorsi muscle was dissected from each of the three sections and a one inch slice was removed from the center of each section. In addition a one inch slice was removed from the center portion of the psoas major muscle and these samples were used for immediate determination of pH, per cent reflectance and expressible moisture. The remaining muscle was ground once through a coarse plate and twice through a fine plate of an Oster food grinder. From this composite, a sample was taken for determination of ether extract, myoglobin and total moisture.

Three muscles, the rectus femoris, biceps femoris and seminembranosus were dissected from the right ham of each carcass. The muscles were trimmed of adhering tissue and 1/2 inch samples were taken from the most proximal and ventral portion (to femur bone) of each muscle for pH, per cent reflectance and expressible moisture determinations. The remainder of each muscle was ground as described above and ether extract, myoglobin and total moisture analyses were made.

Determination of Myoglobin

The determination of myoglobin was a modified cyano method of Poel (1949). The steps in the procedure are as follows:

1. Weigh duplicate 10 gram samples minced muscle to the nearest 0.1 mg.
2. Process 2 minutes in a Waring Blender with 42.5 ml cold water and X ml of 1 N H_2SO_4 . $X = (pH - 3) \times 0.35$
3. Centrifuge 20 minutes at 3000 rpm in 50 ml polyethylene tubes.
4. Decant supernatant liquid into 50 ml tubes and heat slowly in water bath to $54^{\circ}C$., stirring with thermometer.
5. Cool rapidly in ice bath to about $25^{\circ}C$.
6. Transfer to 100 ml. beakers and adjust to pH 7.1 - 7.2 with granular Na_2CO_3 .
7. Return to same tubes used in step 4 and centrifuge 10 minutes at 250 rpm. Decant through Whatman #1 filter paper.
8. Oxidize with 2 or 3 crystals (pin head size) of $K_3Fe(CN)_6$ in 50 ml. Erlenmeyer flasks.
9. Form Mb - CN derivative by adding a small crystal of KCN.

10. Transfer to a "Spectrophotometer 20" cell. Read at 540 mu. and obtain myoglobin concentration, expressed as mg myoglobin/gram of wet tissue, by multiplying the optical density value by 7.50.

Expressible Moisture Determination

Measurements of expressible moisture were made by modifying the rapid method proposed by Grau and Hamm (1953). The modified procedure utilized Whatman #1 filter paper dried 12 hours at 110°F in a convection air oven. The filter paper was then placed in a desiccator over CaSO_4 . When the sample was prepared for measurement, a filter paper sheet was singularly removed from the dessiccator and placed between the plexiglass plates. The sample (0.3 grams) was immediately placed on the midportion of the paper and the plexiglass plates were placed in a Carver Press and held for five minutes at 10,000 pounds pressure per square inch. The muscle and water area were subsequently measured with a polar planimeter and the relative amount of expressible water was recorded as a ratio of muscle area to water area. Each sample was determined in triplicate.

Fat Extraction and Moisture Determination

The total moisture and fat percentages were determined by a modified A.O.A.C. procedure. Fat free cheese cloth and extraction thimbles were dried at 100°F. Approximately a 4 gram sample of minced muscle tissue was weighed in duplicate to the nearest 0.1 mg on a Gram-Atic automatic balance. The tissue was spread over a two layer thickness of cheese cloth, rolled very loosely and put

into a paper extraction thimble and weighed to the nearest 0.1 mg. The samples were dried at 98°F and 20 pounds vacuum, cooled, weighed and total water calculated as loss in weight. Samples were then extracted in a Soxhlet extractor with anhydrous ether for 24 hours and redried for three hours in a vacuum oven at 98°F. The samples were reweighed and additional weight loss expressed as per cent ether extract.

Color Determination

A Photovolt colorimeter was used in the study to determine per cent reflectance from the muscle samples. The per cent reflectance was converted to (Y) equivalents (in per cent relative reflectance compared to MgO) of the recommended Munsell value scale from 0/ to 10/ in which 0/ represents pure black and 10/ pure white.

Determination of pH

A Beckman Zeromatic pH meter was used to determine the pH values of the muscle samples 24 hours post-mortem. A Beckman five inch shielded glass electrode (41263) which had a temperature range of -5°C - 80°C and a pH range of 0-11 was used to obtain pH values from the samples. A five inch sealed calomel electrode with KCl solution was used as a reference electrode.

Statistical Analysis

Analysis of variance was determined on data for: (1) water holding capacity; (2) Munsell color values; (3) hydrogen ion concentration; (4) ether extract; (5) myoglobin concentration, (mg/gram wet tissue); (6) and total moisture of samples. If a significant variance ratio was calculated between lots for a specific characteristic, least significant difference for lots was calculated and applied to the lot means to determine where the differences existed. The same procedure was followed for determining differences between various muscle samples.

RESULTS AND DISCUSSION

There were no significant differences between the ration fed and/or the chemical and physical measurements of the five muscles studied due to sex.

Myoglobin

Mean values for myoglobin concentration of the muscles studied are listed in Table 2. When myoglobin concentrations were compared, differences attributable to ration and muscle location were observed. These data indicate great variation in myoglobin concentration between individual muscles and within the longissimus dorsi.

Significantly higher concentrations of myoglobin were found in the psoas major than the longissimus dorsi, or the three ham

Table 2. Mean values¹ for some pork quality factors within and between selected pork muscles.

Muscles	: Water ² : holding : capacity : value	: Munsell ³ : value	: pH	: Ether : extract : (%)	: Myoglobin : (mg/g)	: Total : moisture : (%)
LD ⁴ (Anterior)	0.43 ^c	5.74 ^g	5.42 ^a	4.46 ^d	0.65 ^a	72.43 ^b
LD (Center)	0.42 ^c	5.44 ^f	5.43 ^a	3.49 ^c	0.67 ^{ba}	72.68 ^b
LD (Posterior)	0.43 ^c	5.52 ^f	5.43 ^a	4.68 ^d	0.71 ^b	71.78 ^a
Rectus Femoris (RF)						
RF (distal)	0.42 ^c	4.88 ^e	5.57 ^g	1.78 ^a	1.27 ^e	75.22 ^f
RF (proximal)	0.49 ^d	4.11 ^a	5.65 ^g			
Biceps Femoris (BF)						
BF (distal)	0.38 ^b	4.89 ^e	5.49 ^{bed}	3.28 ^c	1.15 ^d	73.72 ^c
BF (proximal)	0.34 ^a	4.88 ^e	5.50 ^{cd}			
Semimembranosus (Sem.)						
Sem. (distal)	0.42 ^c	4.69 ^d	5.47 ^{abc}	2.39 ^b	0.93 ^c	74.13 ^d
Sem. (proximal)	0.42 ^c	4.30 ^b	5.47 ^f			
Psoas major	0.42 ^c	4.56 ^c	5.64 ^{de}	2.31 ^b	1.37 ^f	74.75 ^e

¹By least significant difference all values with some superscript are not significantly different at the 5 per cent level.

²Water holding capacity is reported as a ratio of muscle area to water area with the higher value indicating a higher water holding capacity.

³Munsell value is reported to indicate color intensity with the higher values indicating lighter colored muscle tissue.

⁴LD is an abbreviation for the longissimus dorsi muscle.

muscles studied, namely the rectus femoris, biceps femoris and semimembranosus. These ham muscles all contained significantly different concentrations of muscle pigment. The rectus femoris, a darker colored muscle, had the highest myoglobin concentration and the semimembranosus the lowest.

The longissimus dorsi muscle had a significantly lower concentration of myoglobin than the three ham muscles studied. There was also a variation of myoglobin concentration between sections of the longissimus dorsi with the posterior section having a significantly greater myoglobin concentration than the anterior section. However, there was no significant difference between the anterior and center portions.

The variation in concentration of the muscle pigment, myoglobin, from these data cannot be explained. Briskey et al. (1960) also found great variation in myoglobin concentration when eight pork muscles were studied. It has been postulated that these differences were due to variation in muscle functions. Myoglobin was reported to function in the maintenance of high oxygen tension between contractions when blood flow was inadequate to sustain the high rate of oxygen utilization by the tissue. Muscles with large myoglobin concentrations, therefore, are concerned with slow movements over long periods of time (Needham, 1926 and Millikan, 1939).

Effect of Ration on Myoglobin Concentration

The results of this study indicate that myoglobin concentrations can be influenced by the ration fed. An average concentration of all muscles studied for each ration group is listed in Table 3.

Myoglobin concentration was significantly decreased by feeding a ration low in iron. Lot III (9.08 mg Fe/lb feed) had a significantly lower concentration of myoglobin than Lot I (40 mg Fe/lb feed). It is postulated that this decrease in myoglobin concentration was due to a lack of a component of the myoglobin structure; namely iron.

The highest myoglobin concentration was found in muscle samples from Lot VII (23.1 gms NaCl/lb ration after 180 lbs.). This was significantly greater than Lot I (control), but not significantly different than the high iron and copper lots. The increase in myoglobin concentration due to an excess NaCl prior to slaughter cannot be explained on the basis of present theories concerning myoglobin synthesis. It may be noted that the hogs put on the high NaCl ration did not accept the feed or consume it in quantity until three or four days after they were subjected to the ration. The upset from normal feed consumption and the unpalatable ration may have caused a stress on the animals and therefore influenced myoglobin concentration. There were no significant differences in myoglobin concentration between Lot I (control) and Lot IV and V which received high levels of iron and copper. Lot V (600 mg Fe and 60.0 mg Cu/lb feed) tended to

Table 3. Average lot values¹ for some pork quality factors obtained from five selected pork muscles.

Lot	Water ² : holding : capacity	Munsell ³ : value	pH	Ether : extract : (%)	Myoglobin (mg/g)	Total : moisture (%)
1	0.42 ^a	4.93 ^{ba}	5.53 ^{ab}	2.69 ^a	0.93 ^b	73.90 ^a
2	0.39 ^a	4.97 ^b	5.48 ^a	2.93 ^{ab}	0.90 ^b	73.84 ^a
3	0.38 ^a	5.34 ^c	5.54 ^{ab}	2.99 ^{ab}	0.60 ^a	73.90 ^a
4	0.41 ^a	4.82 ^{ba}	5.51 ^{ab}	2.98 ^{ab}	1.00 ^{bc}	73.76 ^a
5	0.42 ^a	4.75 ^{ba}	5.56 ^{ab}	3.89 ^b	1.07 ^{bc}	73.11 ^a
6	0.43 ^a	4.81 ^{ba}	5.55 ^{ab}	3.98 ^b	1.11 ^{bc}	73.10 ^a
7	0.43 ^a	4.65 ^a	5.58 ^b	3.19 ^{ab}	1.17 ^c	73.72 ^a

¹By least significant difference all values with same superscript are not significantly different at the 5 per cent level.

²Water holding capacity is reported as a ratio of muscle area to water area with the higher value indicating a higher water holding capacity.

³Munsell value is reported to indicate color intensity with the higher values indicating lighter colored muscle tissue.

have a higher myoglobin concentration than Lot IV (300 mg Fe and 30.0 mg Cu/lb feed), but the difference was not significant. This is in agreement with work reported by Henry and Bratzler (1960). This may indicate that a plateau is reached after which additional supplementation of Fe and Cu to swine rations is not effective in altering myoglobin concentration of pork muscle.

Bray and co-workers (1959) significantly increased the concentration of myoglobin in veal by feeding high levels of iron and copper. Although the results of the work reported in this thesis is in disagreement with the results reported by Bray et al. (1959), it is recognized that the physiological differences between the two species of the animals studied might be responsible for the different results achieved.

A chelating agent, $\text{Na}_2\text{CaZn EDTA}$ (ethylenediaminetetraacetate), was added to the control ration in Lot II in an attempt to tie up iron consumed by the swine. However, animals from Lot II did not have a significant decrease in myoglobin concentration when compared to the control lot. Because myoglobin concentration was significantly decreased by feeding a ration low in iron, it is assumed that this chelating agent did not tie up enough of the iron ingested to reduce myoglobin synthesis.

Water Holding Capacity, Color and pH

Five individual pork muscles and several locations within some of these muscles were studied with regard to water holding capacity, color and ultimate pH. These data indicate extreme

variation in pH and color (Munsell value) when comparing the longissimus dorsi, rectus femoris, biceps femoris, semimembranosus, and psoas major.

The three sections of the longissimus dorsi muscle were significantly lower in pH and lighter in color than the other muscles studied. The anterior sample was significantly lighter in color than the center and posterior sections; however, there were no significant differences in pH and color between the other two sections of the longissimus dorsi. Water holding capacity, determined by the filter paper method of Grau and Hamm (1953), was not significantly different between the three sections of the longissimus dorsi.

Two ham muscles, the rectus femoris and biceps femoris were the most extreme and variable muscles studied in regard to water retention, color intensity and pH. The rectus femoris showed the most difference when distal and proximal sections of the three ham muscles were compared. The proximal section (to the femur bone) had a significantly higher water holding capacity, darker color and higher pH than the other muscle samples studied, including the distal sample of the rectus femoris. Also, the semimembranosus had a significant difference between sections for pH and color intensity.

It has been reported by Scaife (1955) that color variation is due to the anatomical feature of pork muscle. The results of these data show that the anatomical position of the three ham muscles (ei. their location relative to the femur bone) had

little influence on color intensity, pH or water holding capacity of muscle tissue. The proximal section (to the femur bone) of the semimembranosus had a significantly lower pH, water holding capacity and lighter color than the proximal section of the rectus femoris. However, the proximal section of the semimembranosus also had a significantly higher pH, darker color and higher water holding capacity than the proximal section of the biceps femoris.

The psoas major was significantly darker in color than the other muscles except for the proximal portion of the rectus femoris. It was similar in pH values with the biceps femoris and distal portion (to femur bone) of the rectus femoris, but was significantly different in regard to pH when other muscle sections were compared.

These data indicate a relationship between muscle pH, myoglobin concentration and color intensity. In general, muscles with a higher ultimate pH possessed a darker color and greater myoglobin concentration. Scaife (1955) and Briskey (1960) reported the same relationship. Briskey (1960) reported a correlation of 0.41 between pH and myoglobin concentration. However, Briskey points out that it is possible to attain high ultimate pH values with low myoglobin concentration. It is recognized that myoglobin is present as a result of the functional activity of muscle and not as a result of the high pH. In addition, it is conceivable that the presence of the increased quantity of pigment may have an effect on the reduced level of

glycogen. The greater pigment concentration may permit increased aerobic and anaerobic metabolism prior to and after slaughter and, therefore, contribute to the development of a high pH.

The psaos major, the distal and proximal samples of semimembranosus and the distal sample of the rectus femoris were very similar in expressible water values when compared to the longissimus dorsi. No significant difference between the above muscles or sections were noted when these muscles were compared for water holding capacity.

Water holding capacity did not follow a definite relationship with pH and color determinations. When distal and proximal sections (to femur bone) were compared, the distal portion of the biceps femoris had a significantly higher water holding capacity than the proximal, but these two sections were similar in pH and color values. The semimembranosus showed the opposite effect. There was no significant difference in water holding capacity between the two sections; however, the proximal section had a darker color and higher pH than the distal. The rectus femoris, on the other hand, had significant differences between sections for pH, color and expressible moisture values. The proximal portion was darker in color, higher in pH and had a higher water holding capacity.

This extreme variation indicates that pH may account for only a portion of the variation in water retention in muscle tissue. This is in agreement with work reported by Hamm (1959)

when he suggested that about one-third of the change in hydration (post-mortem) could be explained by the decrease in pH. He also postulated that about two-thirds of the decrease in hydration (post-mortem) was attributable to the dephosphorylation of ATP. Judge et al. (1958) reported a correlation of 0.62 between pH and water holding capacity and Briskey (1960) reported similar values. It may be pointed out however, that the correlation between pH and water retention may be greatly influenced by the position in which the samples were obtained from the muscle. Therefore, a uniform procedure must be followed if data from various studies are compared.

This extreme variation in these pork quality factors cannot be explained by the anatomical position of the muscle. It may be postulated that this variation is due to differences of activity of certain muscle fibers within an individual muscle. A variation in activity of muscle fibers within a muscle might result in a greater demand for oxygen and sources of energy resulting in within muscle variation with regard to ultimate pH, color intensity and water holding capacity.

Effect of Ration on Color Intensity, pH and Water Holding Capacity

Ration had little significant influence on water retention. Lot VII (high NaCl after 180 pounds) had the highest water holding capacity and Lot III (low iron) the lowest, but the difference was not significant. The increase in muscle

water retention by feeding a high concentration of NaCl prior to slaughter may be partly explained by electrolyte concentrations and their relation to volume of body water. The isotonicity of the body fluid which depends mainly upon its concentration of sodium and chloride is maintained constant largely by the retention or elimination of water. A loss of salt is accompanied by a loss of water and the ingestion of salt is followed by water retention. However, the fundamental factors controlling the total volume of body water are not clearly understood (Best and Taylor, 1961, p. 23). The feeding of a high concentration of NaCl prior to slaughter also resulted in a significantly darker colored muscle with a higher pH than found in the lot receiving a chelating agent to tie up the iron consumed.

Except for Lots III and VII there was no significant effect on pH and color of muscles due to ration fed. Average color intensity of the five muscles was significantly decreased by feeding a ration low in iron. It is interesting to note that Lot III also had the lowest concentration of myoglobin. The average color value of the five muscles from animals in Lots IV and V followed closely the pattern of myoglobin concentration of the muscles. Color intensity tended to increase as the iron and copper concentration of the ration increased but the difference was not significant.

Ether Extract and Total Moisture

The fat content and total moisture of the five muscles showed extreme variation between muscles. These values are listed in Table 2. Significant differences in extractable fat were found between the three sections of the longissimus dorsi. The center portion had a significantly lower percentage of fat than the anterior or posterior section. The posterior portion had a higher percentage of extractable fat than the anterior sample, but the difference was not significant. These data tend to support the data reported by McMeekan (1940) and Carpenter et al. (1961).

The three ham muscles had significantly different concentrations of extractable fat. The biceps femoris had the highest percentage of fat and the rectus femoris the lowest. The percent extractable fat of the semimembranosus was not significantly different from the psoas major, but the ether extract values for these two muscles were significantly different from the other muscles studied. The three sections of the longissimus dorsi had a significantly higher percentage of fat than the psoas major, rectus femoris, biceps femoris and semimembranosus. These data are in agreement with results reported by Batcher and Dawson (1960). They related that fat content of one muscle was not always indicative of the fat content of other muscles in the same carcass. Ramsbottom and co-workers (1945) in their study on various beef muscles also found that muscles vary

widely in fat content.

The significant differences in total water concentration of the five muscles appear, as one would expect, to be almost in reverse order of the percentage of fat in the sample.

The ration fed had no significant influence on moisture percentage of the five muscles. Furthermore, no significant differences were found for percent extractable fat except in Lot V (high iron and copper) and Lot VI (no added NaCl). These two lots had a significantly greater percentage of extractable fat than the control lot. It may be noted that animals from these two lots were the "poorest doing" animals and the last individuals to be removed from the feed lot.

SUMMARY

The study of pork quality involves many basic concepts associated with physiological and biochemical phenomenon of skeletal tissue. This study was undertaken to determine the influence of adding various minerals to the swine ration on certain chemical and physical properties associated with pork quality. In addition, it seemed important to study the variation of some pork quality factors within and between selected, individual pork muscles.

Fifty-six Hampshire swine were divided into seven lots with four barrows and four gilts in each lot. The animals were slaughtered at a weight of approximately 200 pounds. The right loin and ham were removed from the carcass after 24 hours of

chilling and muscle samples were obtained from five selected muscles of the ham and loin for chemical and physical analysis.

The rectus femoris, biceps femoris and semimembranosus muscles, respectively, contained decreasing concentrations of myoglobin. Also, the posterior portion of the longissimus dorsi had a significantly greater concentration of muscle pigment than the anterior portion. Myoglobin concentration was significantly decreased by feeding 9.08 mg iron per pound ration and significantly increased by feeding 23.1 mg NaCl per lb ration after 180 pounds.

The rectus femoris showed the greatest difference between distal and proximal (to femur bone) samples when the three ham muscles were compared.

In general, muscles with a higher pH possessed a darker color and greater myoglobin concentration. However, water holding capacity did not follow a definite relationship with pH and color determinations.

The average color value of the five muscles from Lot III was significantly lighter than all other lots. No further significant effect of ration fed on pH and color intensity of muscles was noted.

The three ham muscles had significantly different concentrations of ether extract. Also, the center portion of the longissimus dorsi had a significantly lower percentage of extractable fat than the anterior or posterior portions.

The extreme variation found between muscles and within

muscles for the quality characteristics studied points out the importance of following a rigid, standard procedure when obtaining samples for use in pork quality studies.

ACKNOWLEDGMENTS

Sincere appreciation is expressed to Dr. Robert A. Merkel, major professor, for his help in setting up the project and his assistance and advice during the completion of this study; to Dr. D. H. Kropf and Professor D. L. Mackintosh for their invaluable assistance in the preparation of the manuscript; and to Dr. J. L. Hall of the Department of Biochemistry for his advice and assistance with the chemical analysis.

The author also wishes to thank Dr. Stanley Wearden of the Department of Statistics for his help in the analysis of the data, and the graduate students who participated in the collection of data.

LITERATURE CITED

- American Meat Institute Foundation. The science of meat and meat products. San Francisco: W. H. Freeman and Co., 1960, p. 88-95.
- A.O.A.C. Official Methods of Analysis. Washington D.C.: Association of Official Agricultural Chemists, 1955, p. 386.
- Barron, E. S. G.
Iron-porphyrins and oxidation-reductions. Proc. of the Sixth Res. Conf., American Meat Institute Foundation, 1954, p. 5-17.
- Batcher, O. M. and E. H. Dawson.
Consumer quality of selected muscles of raw and cooked pork. Food Technol. 14: 69-73, 1960.
- Bate-Smith, E. C.
The physiology and chemistry of rigor mortis. Advances in Food Research. 1:1-38, 1948.
- Berman, M. D.
Factors affecting the water retention of beef. V. Variation of the zinc-containing enzymes. J. of Food Sci. 26:422-427, 1961.
- Best, C. H. and N. B. Taylor.
The physiological basis of medical practice. 7th ed. Baltimore: Williams and Wilkins Company, 1961, p. 23.
- Birmingham, E., D. E. Brady, S. M. Hunter, J. C. Grady and E. R. Kiehl.
Fatness of pork in relation to consumer preference. Missouri Agr. Exp. Sta. Bull. No. 549, 1954, p. 8.
- Bray, R. W., E. H. Rupnow, F. M. Hanning, N. N. Allen and R. P. Niedermeier.
Effect of feeding methods on veal production and carcass quality. II. Carcass grades, liver, hide, specific gravity, yield, and chemical analysis of the muscle. J. An. Sci. 18:732-737, 1959.
- Bray, R. W., G. E. Vail, and D. L. Mackintosh.
Influence of freezing upon tenderness in aged beef. J. An. Sci. 1:81, 1942.

- Briskey, E. J., and J. Wismer-Pedersen.
Biochemistry of pork muscle structure. I. Rate of anaerobic glycolysis and temperature changes versus the apparent structure of muscle tissue. *J. of Food Sci.* 26:297-305, 1961a.
- Briskey, E. J. and J. Wismer-Pedersen.
Biochemistry of pork muscle structure. II. Preliminary observations of biopsy samples versus ultimate muscle structure. *J. of Food Sci.* 26: 306-313, 1961b.
- Briskey, E. J., W. G. Hoekstra, R. W. Bray, and R. H. Grummer.
A comparison of certain physical and chemical characteristics of eight pork muscles. *J. An. Sci.* 19:214-225, 1960.
- Briskey, E. J., R. W. Bray, W. G. Hoekstra, P. H. Phillips, and R. H. Grummer.
The chemical and physical characteristics of various pork ham muscle classes. *J. An. Sci.* 18:146-153, 1959a.
- Briskey, E. J., R. W. Bray, W. G. Hoekstra, R. H. Grummer and P. H. Phillips.
The effect of various levels of exercise in altering the chemical and physical characteristics of certain pork ham muscles. *J. An. Sci.* 18:153-157, 1959b.
- Briskey, E. J., R. W. Bray, W. G. Hoekstra, P. H. Phillips and R. H. Grummer.
The effect of exhaustive exercise and high sucrose regimen of certain chemical and physical pork ham muscle characteristics. *J. An. Sci.* 18:173-177, 1959c.
- Callow, E. H.
Comparative studies of meat. I. The chemical composition of fatty and muscular tissue in relation to growth and fattening. *J. of Agr. Sci.* 37:113-119, 1947.
- Carpenter, Z. L., R. W. Bray, E. J. Briskey and D. H. Traeder.
Intramuscular fat distribution in the longissimus dorsi of paired pork loins. *J. An. Sci.* 20:603-605, 1961.
- Clawson, A. J., B. E. Sheffy and J. T. Reid.
Some effects of feeding chlortetracycline upon the carcass characteristics and the body composition of swine and a scheme for the body composition. *J. An. Sci.* 14:1122-1132, 1955.
- Cunha, Tony J.
Swine feeding and nutrition. New York: Interscience Publishers, Inc., 1957, p. 61-65.

- Ginger, D. I., G. D. Wilson, and B. S. Schweigert.
Biochemistry of myoglobin. *Agr. and Food Chem.* 20:
1037-1045, 1954.
- Grau, R., and R. Hamm.
A simple method for the determination of water binding
in muscles. *Naturwissenschaften* 40:29-30, 1953.
- Hamm, R.
Biochemistry of meat hydration. *Proc. of the Eleventh
Research Conf., American Meat Institute Foundation,*
1959, p. 17-23.
- Hanning, F., R. W. Bray, N. N. Allen, and R. P. Niedermeier.
Tenderness and juiciness of veal loin roasts and chop--
a comparison of methods of measuring those qualities.
Food Technol. 11:611-614, 1957.
- Harrington, G., and A. M. Pearson.
Chew count as a measure of tenderness of pork loins
with various degrees of marbling. *J. of Food Sci.* 27:
106-110, 1962.
- Helander, E.
Fat content of skeletal muscular tissue. *Acta. Morpho-
logica Neerlandica-Scandinavia.* 2:3-11, 1959.
- Henry, W. E., E. R. Miller, and L. J. Bratzler.
Effect of repeated injections of iron-dextran upon blood
hemoglobin and hematocrit and upon the iron and myoglobin
concentration and color of the semimembranosus muscle of
swine. *J. An. Sci.* 20:180-182, 1961.
- Henry, W. E., and L. J. Bratzler.
Effect of mineral supplementation on pork muscle color as
measured by spectrophotometry and disk colorimetry.
J. An. Sci. 19:1195-1202, 1960.
- Husaini, S. A., F. E. Deatherage, and L. E. Kunkle.
Studies on meat II. Observations on relation of bio-
chemical factors to changes in tenderness. *Food Technol.*
4:366-369, 1950.
- Jacobson, M., and F. Fenton.
Effects of three levels of nutrition and age of animal on
the quality of beef. I. Palatability, cooking data,
moisture, fat, and nitrogen. *Food Research* 21:415-426,
1956a.

- Jacobson, M., and F. Fenton.
Effects of three levels of nutrition and age of animal on the quality of beef. II. Color, total iron content, and pH. Food Research 21:427-435, 1956b.
- Judge, M. D., V. R. Cahill, L. E. Kunkle, and F. E. Deatherage.
Pork quality II. Physical, chemical, and organoleptic relationships in fresh pork. J. An. Sci. 19:145-153, 1960.
- Judge, M. D., V. R. Cahill, L. E. Kunkle, and W. H. Bruner.
Pork quality I. Influence of some factors on pork muscle characteristics. J. An. Sci. 18:448-452, 1959.
- Judge, M. D., V. R. Cahill, L. E. Kunkle, and F. E. Deatherage.
Physical, chemical and organoleptic relationship in fresh pork. J. An. Sci. 17:1157, 1958.
- Kauffman, R. G., R. W. Bray, and M. A. Schaars.
Price vs. marbling in the purchase of pork chops. Food Technol. 15:22-24, 1961.
- Kauffman, R. G.
Pork marbling. Proc. 13th An. Reciprocal Meat Conf., 1960, p. 31-54.
- Kelly, R. F., R. W. Bray and P. H. Phillips.
The influence of chlortetracycline supplementation of the ration on distribution, quantity and quality of fat deposited in swine. I. Metabolic effect in relation to carcass composition. J. An. Sci. 16:74-84, 1957.
- Kropf, D. H., R. W. Bray, P. H. Phillips and R. H. Grummer.
Effect of protein level and quality in swine rations upon growth and carcass development. J. An. Sci. 18:755-762, 1959.
- Kropf, D. H.
The effect of protein quality and supplementation of swine rations with lysine and tryptophan upon nitrogen metabolism, growth and carcass composition of swine. Ph.D. Thesis, Univ. of Wisc., 1956.
- Kurtz, G. W.
The chemistry of meat flavor--a review. Proc. of the Eleventh Res. Conf., American Meat Institute Foundation, 1959, p. 95-97.
- Lawrie, R. A.
Abnormally low ultimate pH in pig muscle. Nature. 182: 807-808, 1958.

- Lawrie, R. A.
Effect of enforced exercise on myoglobin concentration in muscle. *Nature*. 171:1069, 1953.
- Lawrie, R. A.
Some observations on factors affecting myoglobin concentration in muscle. *J. of Agr. Sci.* 40:355, 1950.
- Lockett, C., C. E. Swift and W. L. Sulzbacher.
Some relations between the chemical and physical characteristics of bovine muscles. *J. of Food Sci.* 27:36-41, 1962.
- Mackey, A. O., and A. W. Oliver.
Sampling pork loins for cooking tests. *Food Research* 19:298-301, 1954.
- McCarthy, J., and D. L. Mackintosh.
Some observations on the pH of pork under various conditions. *Food Technol.* 7:167-171, 1953.
- McMeekan, C. P.
Growth and development in the pig with special reference to carcass quality characters. *I. J. Agr. Sci.* 30:276, 1940.
- Merkel, R. A., R. W. Bray, R. H. Grummer, P. H. Phillips, and G. Bohstedt.
The influence of limited feeding, using high fiber rations, upon growth and carcass characteristics of swine. *J. An. Sci.* 17:3-12, 1958.
- Millikan, G. A.
Muscle hemoglobin. *Physiol. Rev.* 19:503-523, 1939.
- Murphy, M. O., and A. F. Carlin.
Relation of marbling, cooking yield and eating quality of pork chops to backfat thickness on hog carcasses. *Food Technol.* 15:57-63, 1961.
- Needham, D. M.
Red and white muscle. *Physiol. Rev.* 6:1-27, 1926.
- Niedermeier, R. P., N. N. Allen, R. D. Lance, E. H. Rupnow, and R. W. Bray.
Effect of feeding methods on veal production and carcass quality. I. Rate of gain, stomach capacity, vitamin A, iron, and hemoglobin values. *J. An. Sci.* 18:726-731, 1959.
- Poel, W. E.
Effect of anoxic anoxia on myoglobin concentration in striated muscle. *Am. J. Physiol.* 156:44-51, 1949.

- Pork Carcass Evaluation Committee. Cutting procedure for pork carcasses. Proc. Fifth An. Reciprocal Meat Conf., 1952, p. 120-121.
- Ramsbottom, J. M., E. J. Strandine, and C. H. Koony. Comparative tenderness of representative beef muscles. Food Research 10:497-509, 1945.
- Saffle, R. L. and L. J. Bratzler. The effect of fatness on some processing and palatability characteristics of pork carcasses. Food Technol. 13:236-240, 1959.
- Sair, L., and W. H. Cook. Relation of pH to drip formation in meat. Can. J. Research. 16:255-258, 1938.
- Satorius, M. J., and A. M. Child. Problems in meat research. I. Four comparable cuts from one animal. II. Reliability of judges' scores. Food Research 3:627-635, 1938.
- Sayre, R. N., E. J. Briskey, W. G. Hoekstra and R. W. Bray. Effect of preslaughter change to a cold environment on characteristics of pork muscle. J. An. Sci. 20:487-492, 1961.
- Scaife, J. F. Variation of ultimate pH within pig muscle. J. of the Sci. of Food and Agr. 6:467-471, 1955.
- Schweigert, B. S. Chemistry of meat pigments. Proc. of the Eight Res. Conf., American Meat Institute Foundation, 1956, p. 61-65.
- Sheehy, E. S. Minerals and vitamins in pig feeding. Nutr. Abs. and Reviews, 2:221-228, 1932.
- Sherman, P. The water binding capacity of fresh pork. I. The influence of sodium chloride, pyrophosphate, and polyphosphate on water absorption. Food Technol. 15:79-86, 1961.
- Snedecor, G. W. Statistical methods. 5th ed., Ames, Iowa: The Iowa State University Press, 1959, p. 10.

- Swift, C. E., M. D. Berman, and C. Lockett.
Factors affecting the water retention of beef. II.
Variation in some pH determinants among eight muscles.
Food Technol. 14:74-79, 1960.
- Swift, C. E., and M. D. Berman.
Factors affecting the water retention of beef. I.
Variation in composition and properties among eight
muscles. Food Technol. 13:365-370, 1959.
- Urbain, M. C., D. A. Zessin, and G. D. Wilson.
Observations on a method of determining the water
binding properties of meat. J. An. Sci. 21:9-13, 1962.
- Weir, C. E.
The variation in tenderness in the longissimus dorsi
muscle of pork. Food Technol. 7:500-501, 1953.
- Wierbicki, E., L. E. Kunkle, V. R. Cahill, and F. E. Deatherage.
Post mortem changes in meat and their possible relation
to tenderness together with some comparisons of meat from
heifers, bulls, steers, and diethylstilbestrol treated
bulls and steers. Food Technol. 10:80-86, 1956.
- Wilson, G. D., I. D. Ginger, B. S. Schweigert, and W. J.
Aunan.
A study of the variation of myoglobin concentration in
two toned hams. J. An. Sci. 18:1080-1086, 1959.
- Wintrobe, M. M., G. E. Cartwright, and C. J. Gubler.
Studies on the function and metabolism of copper. J.
Nutr. 50:395-419, 1953.
- Wisner-Pedersen, J.
Quality of pork in relation to rate of pH change post
mortem. Food Research 24:711-727, 1959.

VARIATION IN SOME PORK QUALITY FACTORS WITHIN
AND BETWEEN SELECTED PORK MUSCLES

by

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B. S., University of Wisconsin, 1960

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

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Manhattan, Kansas

1962

The study of pork quality involves many basic concepts associated with physiological and biochemical phenomenon of skeletal tissue. This study was undertaken to determine the influence of adding various minerals to the swine ration on certain chemical and physical properties associated with pork quality. In addition, it seemed important to study the variation of some pork quality factors within and between selected, individual pork muscles.

Fifty-six Hampshire swine were divided into seven lots with four barrows and four gilts in each lot. The pigs were fed the following ration from weaning to slaughter weight: Lot I, control ration which contained 40.18 mg of iron and 6.79 mg copper per pound of ration; Lot II, control ration plus 400 mg $\text{Na}_2\text{Ca Zn EDTA}$ (ethylenediaminetetraacetate) per pound ration; Lot III, low iron ration which contained 9.08 mg iron and 2.82 mg copper per pound ration; Lot IV, control ration plus 300 mg iron and 30.0 mg copper per pound ration; Lot V, control ration plus 600 mg iron and 60.0 mg copper per pound ration; Lot VI, control ration without added sodium chloride; lot VII, control ration to 180 pounds, after 180 pounds they received the control ration plus 23.1 gms sodium chloride per pound ration.

The animals were slaughtered at a weight of approximately 200 pounds. The right loin and ham was removed from the carcass after 24 hours of chilling and muscle samples were obtained from the anterior, center and posterior sections of the longissimus dorsi, semimembranosus, biceps femoris, rectus femoris, and the

psoas major muscle. The determination of myoglobin (modified cyano method of Poel (1949), and ether extract and total moisture (modified A.O.A.C. procedure) were made on the above muscle samples. In addition color intensity, pH and expressible moisture determinations were obtained from the distal and proximal (to femur bone) samples from the rectus femoris, biceps femoris and semimembranosus muscles, the three portions of the longissimus dorsi and the psoas major muscle.

The three ham muscles contained significantly different concentrations of myoglobin. The posterior portion of the longissimus dorsi had a significantly greater concentration of muscle pigment than the anterior portion. Myoglobin concentration was significantly decreased by feeding 9.08 mg iron per pound ration and significantly increased by feeding 23.1 mg NaCl per pound ration after 180 pounds.

The anterior portion of the longissimus dorsi was significantly lighter in color than the center or posterior sections. The rectus femoris showed the most extreme difference when distal and proximal sections of the three ham muscles were compared. The proximal section had a significantly higher water holding capacity, darker color and higher pH than all other muscle samples. In general, muscles with a higher pH possessed a darker color and greater myoglobin concentration. However, water holding capacity did not show a definite relationship with pH and color determinations. When distal and proximal sections were compared, the distal portion of the biceps femoris had a

significantly higher water holding capacity than the proximal, but these two sections were similar in pH and color values.

The semimembranosus showed the opposite effect.

The average color value of the five muscles from Lot III was significantly lighter than all other lots. No further significant effect of ration fed on pH and color intensity of the muscles was noted.

The three ham muscles had significantly different concentrations of ether extract. Also, the center portion of the longissimus dorsi had a significantly lower percentage of extractable fat than the anterior or posterior portions.

The extreme variation found between muscles and within muscles for the quality characteristics studied points out the importance of following a rigid, standard procedure when obtaining samples for use in pork quality studies.